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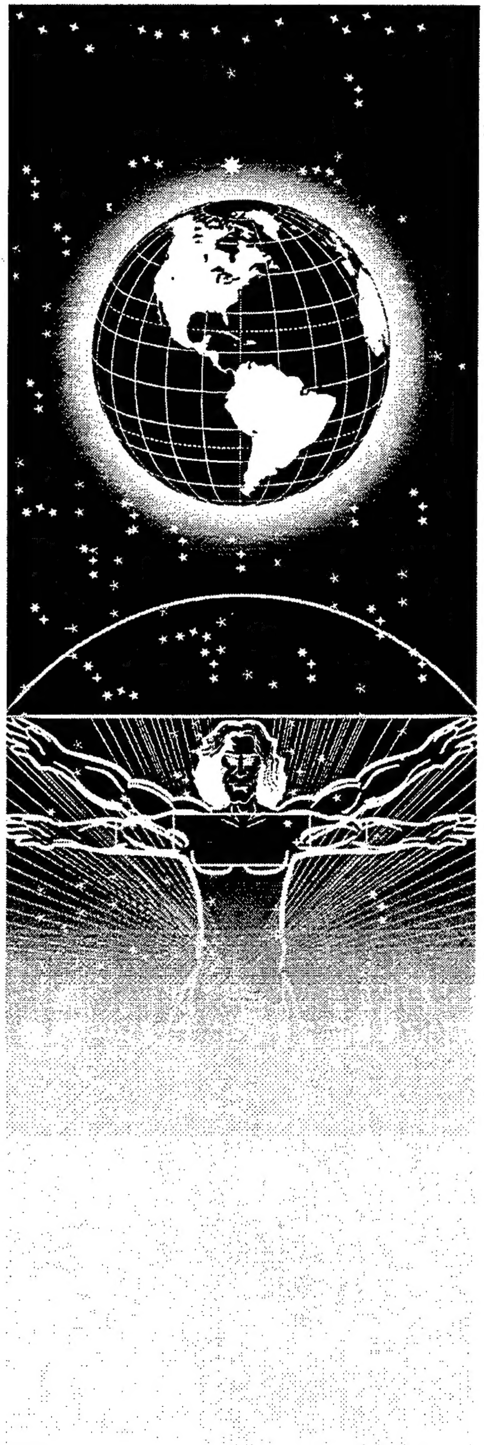

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Scratch Resistance Testing of Pilot Helmet Visors Using a New Scratch Resistance Tester

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December 1996

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The causes for removing pilot helmet visors from service were investigated as part of the Armstrong Laboratory's Advanced Aircrew Vision Protection (AAVP) program. The purpose of the investigation was to identify the factors which limit visor service life so that better technologies, specifications, or procedures could be developed and applied to the laser eye protection (LEP) visors being transitioned to the Human Systems Center (HSC) under the AAVP program. It was determined that the single cause of visor degradation which resulted in removing it from service was scratches in or delamination of the surface hardcoating (Reference AL/OE-TR-1996-0117, Failure Mechanisms in Pilot Helmet Visors). As a result of these findings, the requirements for scratch resistance of pilot helmet visors were further examined. It was found that no specific scratch resistance requirements or specifications are applied to pilot helmet visors. Abrasion resistance and coating adhesion are specified in MIL-V-43511C and MIL-C-83409 but not scratch resistance. A new apparatus, the Maier Scratch Resistance Tester (MSRT), for testing the scratch resistance of optical coatings was invented and two prototype Maier scratch resistance testers (MSRTs) were fabricated. These testers were used to test the scratch resistance of pilot helmet visors from three different manufacturers. The tests on the visors were performed by two different operators, using two different MSRTs with one type of stylus. The tests described here were the initial tests performed with the new MSRT apparatus and had the following objectives: 1) to investigate the repeatability and consistency of the results obtained by different operators and for different MSRTs; and 2) to establish baseline scratch resistance characteristics, values, and variability for existing hard coatings which are used on Air Force pilot helmet visors. The MSRT, the procedures for its operation, possible variations, advantages of the MSRT, and the results of the initial scratch resistance testing performed with the prototype MSRTs are described here.

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INTRODUCTION

The causes for removing pilot helmet visors from service were investigated as part of the Armstrong Laboratory's Advanced Aircrew Vision Protection (AAVP) program. The purpose of the investigation was to identify the factors which limit visor service life so that better technologies, specifications, or procedures could be developed and applied to the laser eye protection (LEP) visors being transitioned to the Human Systems Center (HSC) under the AAVP program. It was determined that the single cause of visor degradation which resulted in removing it from service was scratches in or delamination of the surface hardcoating (Reference AL/OE-TR-1996-0117, Failure Mechanisms in Pilot Helmet Visors). As a result of these findings, the requirements for scratch resistance of pilot helmet visors were further examined. It was found that no specific scratch resistance requirements or specifications are applied to pilot helmet visors. Abrasion resistance and coating adhesion are specified in MIL-V-43511C and MIL-C-83409 but not scratch resistance. A new apparatus, the Maier Scratch Resistance Tester (MSRT), for testing the scratch resistance of optical coatings was invented and two prototype Maier scratch resistance testers (MSRTs) were fabricated. These testers were used to test the scratch resistance of pilot helmet visors from three different manufacturers. The tests on the visors were performed by two different operators, using two different MSRTs with one type of stylus. The tests described here were the initial tests performed with the new MSRT apparatus and had the following objectives: 1) to investigate the repeatability and consistency of the results obtained by different operators and for different MSRTs; and 2) to establish baseline scratch resistance characteristics, values, and variability for existing hard coatings which are used on Air Force pilot helmet visors. The MSRT, the procedures for its operation, possible variations, advantages of the MSRT, and the results of the initial scratch resistance testing performed with the prototype MSRTs are described here.

MAIER SCRATCH RESISTANCE TESTER (MSRT)

Background

The ability of various surfaces to resist scratches is important in deciding the merits of the surfaces to perform under the conditions of expected use. A means of quantitatively and/or qualitatively measuring the resistance of surfaces to scratches is needed. An apparatus and method for performing scratch resistance testing, the MSRT, has been developed and is described below.

Although the scratch resistance test described here could be applied to many different types of coatings, finishes, or surfaces, only the scratch resistance of coatings applied to ophthalmic eyewear such as glasses, goggles, and visors is considered in this report. Currently the specifications and test methods for ophthalmic eyewear address the

abrasion resistance of the protective coatings but not the scratch resistance. It is implied that the abrasion resistance of a surface is representative of the scratch resistance. This is not necessarily true. In abrasion tests, a specified abrasive material is rubbed on the surface being tested with a prescribed force and motion. The motion is often back and forth or circular for a prescribed number of cycles. The criteria for passing or failing the test vary from visual inspection to measurement of the percent of increase in light scattered by the surface. Some of the common abrasion tests include the eraser test, the Tabor abrader test, the cheesecloth test, and the steel-wool test.

The mechanism for producing scratches on a surface differs from the mechanisms which produce abrasions. A scratch typically results when a sharp, hard object is dragged across the surface with a force pressing the sharp object against the surface. This is often a single event which produces a single scratch on the surface. Multiple occurrences of this type of single event produce multiple scratches. The MSRT produces the scratching mechanism in a controlled manner such that the scratch resistance of the surface can be determined directly.

Description

The MSRT apparatus for scratch resistance testing is illustrated in several views in Figure 1. The apparatus consists of a stylus (1) which is free to slide up and down in the stylus guide (2) of the stylus guide block (3). The stylus can have various types of tips (4) depending on the particular test that is desired. The tip of the stylus can be of different designs such that the scratching mechanism which is expected in the use of the surface can be approximated. Three different stylus tip designs are shown in Figure 2. The stylus is pushed down by the force of its own weight onto the surface being tested. The guide block has wheels (5) attached which permit it to be easily rolled across the surface under test. The guide block has a handle (6) attached which permits the operator to hold the apparatus and to pull it across the surface being tested. Different weights (7) can be placed on the upper end of the stylus to vary the force with which the stylus tip is pressed against the surface being tested. A milled guide (8) in the side of the stylus shaft prevents the stylus from rotating as it is dragged across the surface.

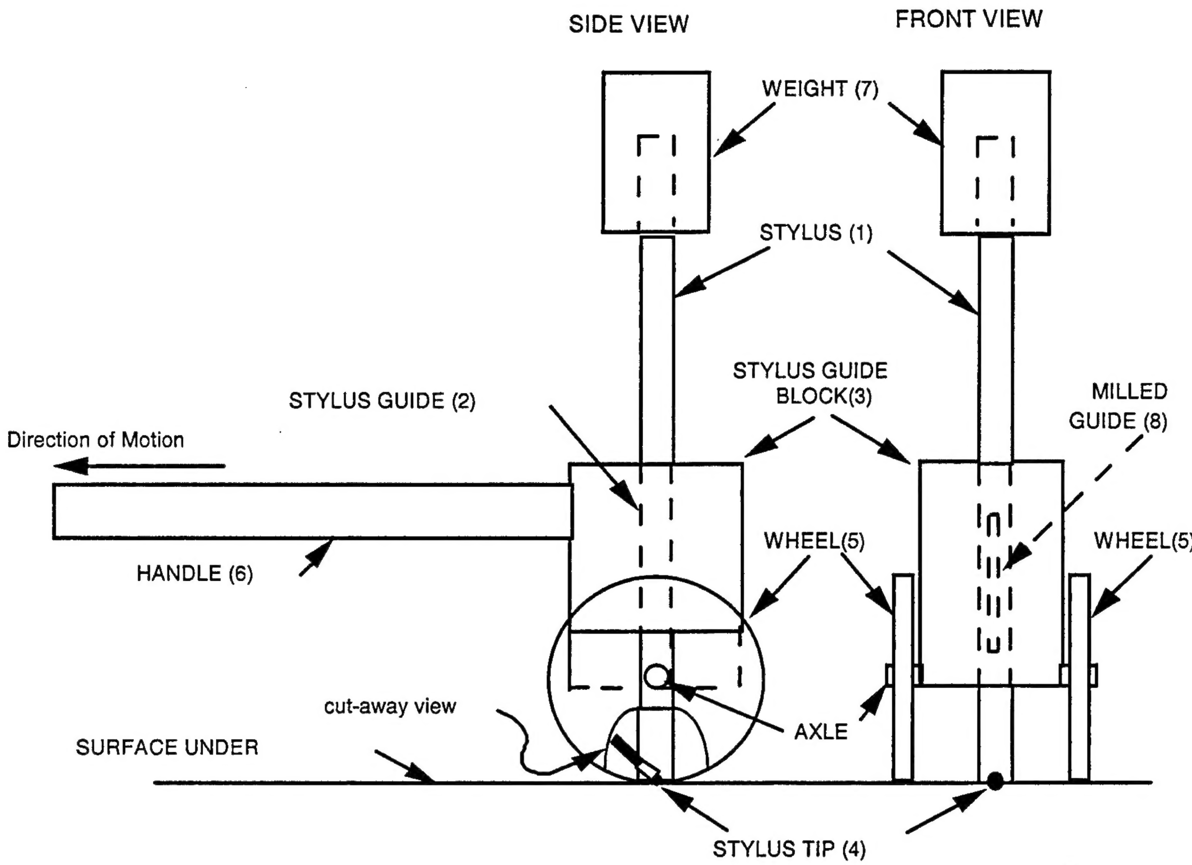

Figure 1: Schematic illustration of Maier Scratch Resistance Tester.

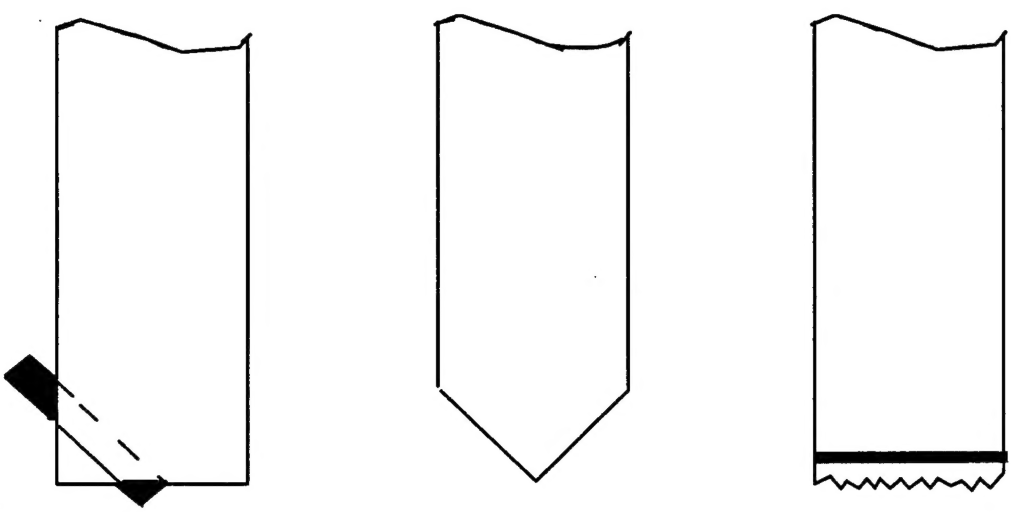

Figure 2: Illustration of three different stylus tips.

Operation

The operation of the scratch resistance tester is as follows. The wheels of the apparatus are placed on the surface to be tested such that the stylus is vertical. The stylus slides in the stylus guide such that the force of the weight of the stylus is applied to the stylus tip which is resting on the surface. The handle is used to pull the apparatus in a straight-line motion such that the wheels roll on the surface and the tip of the stylus is dragged across the surface. The stylus should be kept in a vertical direction during the dragging. A single dragging of the stylus tip is performed. The distance through which the stylus is dragged will depend on the surface being tested. The surface is then examined visually, with or without a magnifier, to ascertain whether or not the surface was scratched. A weight is added to the stylus, and the dragging operation is performed again in a different position on the surface. The weight is increased until a scratch occurs. For the testing of optical coatings the criterion for occurrence of a scratch on the surface would be any scratch which was detectable with the unaided eye under ideal lighting conditions. The scratch resistance of a coating could be specified such that no visible scratch would occur with a prescribed weight of stylus and with a prescribed stylus tip. The test method can also be used as a comparative test between different optical coatings.

Variations

The basic configuration and operation of the MSRT and its operation have been discussed. There are, however, numerous variations of the basic concept which could be embodied in the MSRT. The type of stylus tip used in the tester can be varied as discussed above depending on the particular type of test desired. Figure 2 illustrates three types of stylus tips which could be used with the same tester. The rod-at-an-angle type tip can be constructed with different diameters of rod, the conical tip can be constructed with different radii on the point of the cone, and the grit-tipped stylus can be made with varying grits. The weights that are added to the stylus provide a completely variable level or degree of severity of the scratch resistance test. A single-stylus tester was described, but a multiple-stylus tester as illustrated in Figure 3 could be constructed. With a multiple-stylus tester, different stylus tips could be used in a single test, multiple styluses of the same type could be used with varying amounts of weight on each stylus, or any combination of weight and stylus tip can be used. The stylus guide illustrated is a precision hole drilled through the depth of the stylus guide block. For a more precision device, a linear bearing could be used to guide the stylus, thus reducing the friction which resists the upward and downward sliding of the stylus. Once the MSRT weight for producing a scratch on a particular surface has been established, the weight on the stylus could be fixed at the appropriate value and a pass/fail test could be performed.

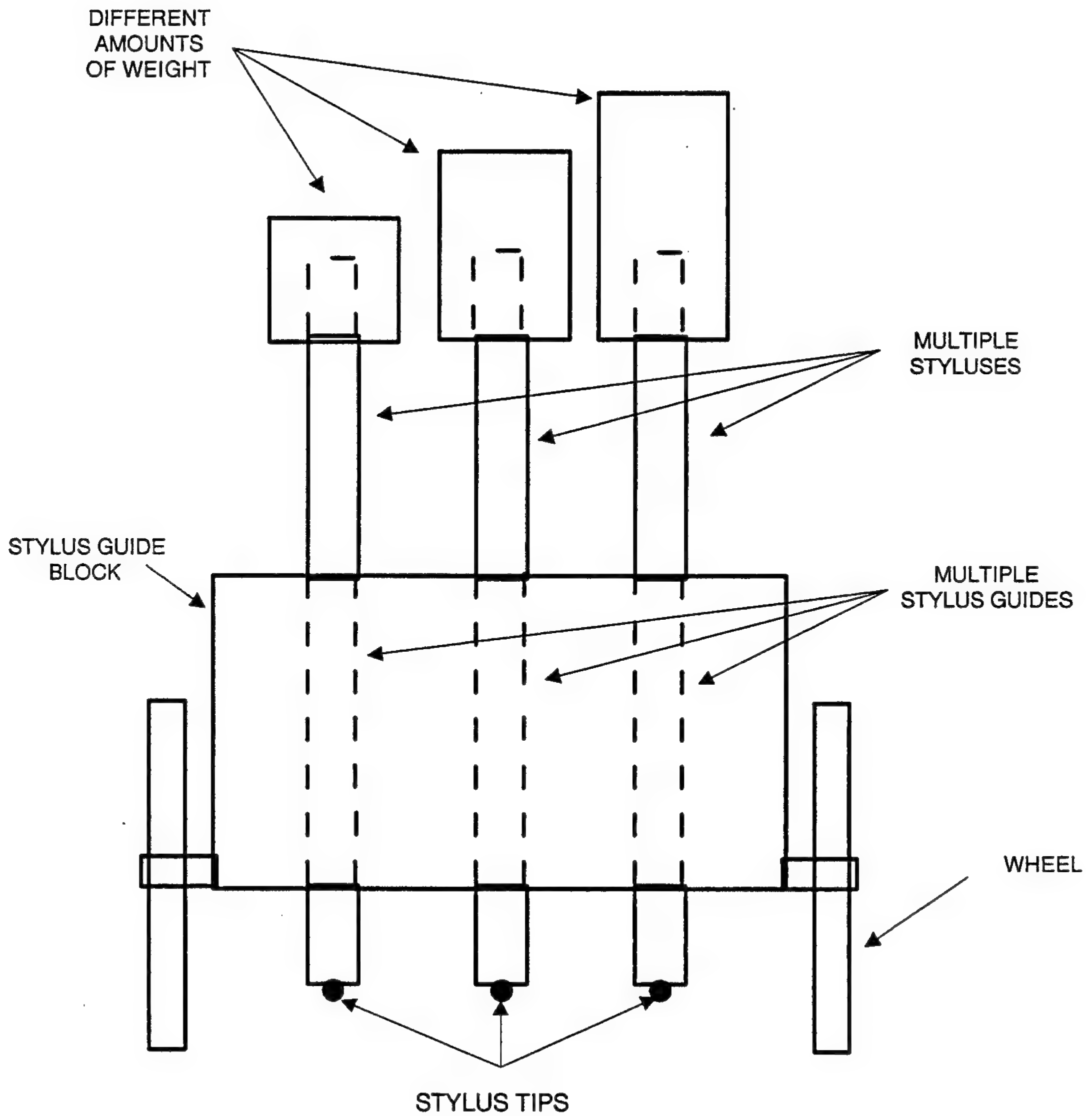

Figure 3: Illustration of multiple-stylus scratch tester.

Features and Advantages of the MSRT

The features of the MSRT provide several advantages in terms of its application and use. Some of these features are enumerated below:

1. It is simple and inexpensive to construct and use.
2. It permits the testing of surfaces which are not flat, such as the surfaces of ophthalmic eyewear.
3. It provides the flexibility of testing the scratch resistance of a surface under conditions which are representative of the expected scratch mechanisms which will be encountered during use. The use of different styluses and/or weights increases this flexibility.
4. The MSRT can be constructed as a single- or multiple-stylus apparatus.
5. It can be used as an absolute or comparative measure of the scratch resistance of a surface.

BASELINE TESTS OF PILOT HELMET VISORS USING THE MSRT

Test Description and Objectives

Tests to determine baseline values for parameters related to scratch resistance of protective coatings on polycarbonate visors were performed with the two MSRTs. The exact nature of the protective coatings on the visors which were tested is not known. Manufacturers typically will not divulge the exact nature of the coatings. It is assumed that the coatings are polysiloxane-dip type coatings approximately 5- to 10-µm thick. Knowledge of the exact nature of the protective coatings was not needed for this study since comparative tests were performed on "as delivered" visors. The two MSRTs were used by two different operators to perform scratch testing on 20 Air Force pilot helmet visors. Ten neutral gray visors (also called sun visors) manufactured by Gentex Optics, Inc., five laser visors manufactured by EDO Barnes, and five FV-6 laser visors manufactured by Glendale Protective Technologies, Inc. were used for these tests. Three locations on the front and back sides of each visor (six locations per visor) were tested. The objective of these initial tests was to collect data on the consistency (or variability) of the different parameters which are involved with the new test and test method employing the MSRT and to determine expected baseline values which can be used for further refining the MSRT and the test methods. The following possible variabilities of the scratch resistance of the surfaces and of the scratch resistance test were considered:

1. Variations of the scratch resistance of the optical coating produced by the same manufacturer - visor-to-visor variability.
2. Variations in the scratch resistance at different locations on the same visor - location-to-location variability.

3. Variations of the values for scratch resistance for optical coatings from different manufacturers - manufacturer-to-manufacturer variability.
4. Variations of the scratch resistance values for different MSRTs with the same type of stylus - MSRT-to-MSRT variability.
5. Variations of the scratch resistance values obtained by different operators using the same MSRT on the same visor - operator-to-operator variability.

MSRT and Stylus Description

A general description of the MSRT was given above. There are many possible configurations of the MSRT which can be employed. This section discusses the two specific MSRTs used to perform the baseline tests of the optical coatings on pilot helmet visors.

The objective of the MSRT and the tests performed with it is to provide a measure of the scratch resistance of the surface being tested under conditions which are expected to be encountered during use. The specific type of stylus used in the MSRT can be chosen to be representative of the mechanisms or objects which are expected to cause scratches to the surface.

For the testing of the visors, a stylus with a tip similar to the one depicted in Figure 2, Tip #1, was used (see Figure 4). A solid tungsten carbide drill bit, 5/64 inch (.0781") in diameter, was used to fabricate the stylus tips. The upper portion of carbide drill bit which has no drill flutes was used to obtain short lengths of tungsten carbide rod. These lengths of cylindrical rod (approx. .375" long) were cut such that the ends of the rod were perpendicular to the axis of the cylinder. The end of the rod, which was to be the stylus tip, was highly polished using a lapping fixture and varying grits of lapping paper. The finest lapping paper was 3-μm grit. The final polish was performed using a slurry of jeweler's rouge. The lapping fixture held the carbide rod perpendicular to the lap. Thus a right circular cylinder of tungsten carbide was obtained for use as the MSRT stylus tip. The same process was used to produce two tungsten carbide tips. A .25" diameter stainless steel rod was used as the stylus of the MSRT. A 5/64" hole was drilled from the center of the end of the stylus at an angle to the axis of the stylus rod. The tungsten carbide tip was inserted in the hole and cemented in place. Figure 4 shows the stylus and tip configuration that was used. An angle of 45° for both ϕ and θ was used to produce the first two styluses. This angle proved to be inappropriate, since the 45° stylus produced scratches in the visor coatings with little or no weight added to the stylus. Two more styluses were produced with the angle θ nominally equal to 60°. Because of inaccuracies in the drilling process, the angle θ was measured to be 57°. By changing the angle of the tip in the stylus, the amount of surface area of the tip bearing on the visor surface was changed. The amount of weight which was required to be added to the stylus in order to produce a scratch in the visor surface was thus changed. The desired value for the weight which would produce a scratch was approximately the weight of the visor

(73 - 100 grams or 2.58 - 3.53 oz). This weight would be equivalent to the visor being dragged across an object under its own weight.

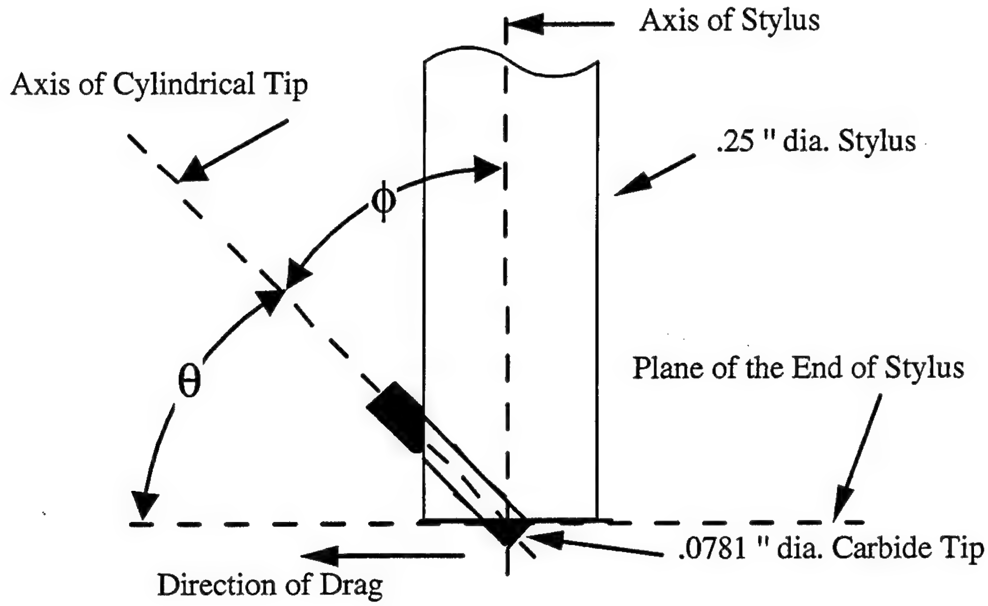

Figure 4: Illustration of the stylus and tip of the Maier Scratch Resistance Testers used to perform pilot helmet visor tests.

The amount of weight that must be added to the MSRT stylus in order to produce a scratch when the stylus is dragged across the surface is the measure of the scratch resistance. The more weight that can be added before a scratch occurs, the higher the scratch resistance. The MSRT numbers for scratch resistance are the amounts of weight in grams added to the MSRT stylus that just produced a permanent scratch visible to the unaided eye. For the baseline tests, six weights which could be placed individually or stacked in any combination on the end of the stylus were fabricated. The six weights were nominally 5, 10, 15, 25, 25, and 60 grams. With these six weights, any amount of weight up to 140 grams could be obtained in 5-gram increments. The tolerances on the individual weights was ± .1 grams. While performing the tests, the weights were added to the end of the stylus until a scratch resulted. The highest value of weight which did not produce a scratch and the value of weight which just produced a scratch were recorded. The weight of the stylus was 23.85 grams. The stylus weight was not included in the MSRT values, since it is a constant bias. The stylus weight may be added to MSRT values to obtain the absolute amount of weight required to produce a scratch.

The two MSRTs which were fabricated for performing the baseline tests had a .25" inner diameter linear bearing which guided the stylus. This bearing allowed the stylus to move up and down with minimum friction and minimum wobble in the angular

orientation. A milled guide in the side of the stylus prevented the stylus from rotating about the stylus axis.

Test Methods and Findings

The method of operation of the MSRT used for the baseline tests was as described above. The two PVC wheels of the MSRT were placed on the visor surface and rolled such that the tip of the stylus was dragged across the visor surface. The MSRT stylus was maintained vertical and perpendicular to the surface. The direction of the dragging relative to the cylindrical tip was as shown in Figures 1 and 4. Since the visor surfaces are curved, the visor was rotated slightly as the MSRT was dragged horizontally. Weights were added to the stylus until a scratch was produced. It was found that the occurrence of a scratch in the protective coatings of the visors was a very definitive event (i.e., either a very definitive scratch occurred or no scratch occurred). When the threshold of weight needed to produce a scratch was exceeded, the tip of the stylus broke through the coating and a scratch was produced for the length of the dragging motion. An audible scratching sound could be heard. This breaking through of the protective coating has been called the "thin ice" or "crust on snow" effect. Because of this crust effect, it was found that the tip of the MSRT stylus could not be allowed to rest on one spot for a period of time prior to performing the dragging motion. More consistent results were obtained if the MSRT was moved slightly in the opposite direction of the dragging just prior to beginning the drag.

Test Results

The values of the weights which produced scratches were recorded and later were entered in Excel spreadsheets. The summary spreadsheets containing all of the data collected during the baseline tests are included as Appendix A. All of the data is contained in these spreadsheets. It is, however, difficult to interpret such a large number of data points (480). This section will present the data in tabular and graphical form as a function of the different variables which were being investigated. Discussion of the results is included. Average values are used so that the trends may be more readily observed.

The variability of the MSRT value as a function of location on the 20 different visors was investigated. Tests were performed at three locations on the front and back of each visor. Two operators used two different MSRTs to test the visors. The styluses that were used were fabricated identically, but the potential variability of the stylus was considered. Tables 1 and 2 show the average variation of the MSRT values for different operators and different MSRT styluses. The variation was calculated by taking the difference between the high and low MSRT values measured at the three points on one side of a visor. These differences were then averaged for each side, each operator, and each stylus. Tables 1 and 2 also show that the variation in the MSRT as a function of

location (center, left, and right) on each individual visor was very small. The maximum MSRT variation across a particular side of any visor was as much as 20 but typically was no more than 5 or 10. Since 5 is the incremental MSRT difference, these values are considered to be small.

TABLE 1: AVERAGE VARIATION IN MSRT VALUES-TESTER S/N 001-STYLUS #3

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	2.3	3.2	2.3	4.2
FV-6	0.0	2.3	1.3	2.3
BARNES	1.0	3.3	1.3	3.0

TABLE 2: AVERAGE VARIATION IN MSRT VALUES- TESTER S/N 002-STYLUS #4

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	.5	3.0	.7	3.2
FV-6	1.0	3.0	1.0	2.3
BARNES	.7	1.7	.3	1.7

The MSRT values obtained for the three different visor types, representing three manufacturers, were compared. Average values were obtained by averaging the MSRT values obtained at all locations on a particular side of the visors for a particular operator using a particular MSRT. Since these were the first scratch resistance tests performed with the MSRT, typical or expected numbers for the MSRT values had not been established. The average values of the MSRT obtained for the visors from each manufacturer as function of operator and visor side are given in Tables 3 and 4. Table 3 gives the values obtained with stylus 3 in MSRT S/N 001, and Table 4 gives the values obtained with stylus 4 in MSRT S/N 002.

TABLE 3: AVERAGE MSRT VALUES - TESTER S/N 001-STYLUS #3

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	41.8	75.8	53.0	87.2
FV-6	69.0	104.3	89.7	124.0
BARNES	39.3	78.0	51.7	78.7

TABLE 4: AVERAGE MSRT VALUES - TESTER S/N 002- STYLUS #4

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	35.0	60.8	41.2	60.0
FV-6	38.7	76.7	47.0	78.3
BARNES	11.3	37.7	10.7	39.7

The tabulated values from Tables 3 and 4 are shown graphically in Figures 5 and 6. The information shown in these tables and figures is further broken down to better analyze the different variables. The MSRT values obtained for front and rear of the visors from the three manufacturers are shown graphically in Figures 7 through 10. Separate figures for each operator and each stylus are provided. Figures 11 and 12 show graphically the MSRT values obtained by the two operators as a function of the stylus used (only the front locations are shown).

The tables and plots of the average MSRT values (the grams of weight added to the stylus to produce a scratch) show significant and consistent differences in values obtained for the visors from different manufacturers, values obtained by different operators, and values obtained with the two different styluses. These results will be analyzed and discussed below.

Consistent relative measures of the scratch resistance of the coatings, manufacturer to manufacturer, were obtained with the MSRT. The coatings on the FV-6 (Glendale) visors were measured to be more scratch resistant than those on the sun (Gentex) and the Barnes (EDO Barnes) visors. The coatings on the sun and Barnes visors had approximately the same MSRT values, with the Barnes coating being less scratch resistant in some instances. The relative rankings of scratch resistance were independent of operator or stylus. The average MSRT values for visors from the three manufacturers with maximum and minimum values are shown in Figures 13 and 14. Only the values for the front side and one stylus are shown for each of the two operators so that the relative average values and maximum and minimum values manufacturer to manufacturer can be more readily compared. The MSRT maximum and minimum values for one of the sun visors (visor #16) was excluded because this visor evidenced scratch resistance which was almost double any of the other nine sun visors.

The operator-to-operator variation was examined. The values in Table 5 were obtained by calculating the absolute value of the difference between MSRT values obtained by the two operators at a particular location on a visor with a particular stylus then computing the average of these values. These values are also the same as the difference in the average values given in Tables 3 and 4 since the variation was in one direction. Figures 15 and 16 show graphically the variation in MSRT values operator-to-operator. It is observed that the MSRT values obtained by Operator 2 were consistently higher than the values obtained by Operator 1. The Operator 2 values were

approximately 20 to 40 grams higher. There are several possible explanations for this apparent bias between operators. Operator 1 performed all tests on all visors prior to Operator 2 beginning testing. The stylus tips of the MSRTs may have become less sharp after repeated use by Operator 1. This would explain higher values obtained by the second operator. Another possible explanation of the differences would be that the operating method or technique used by the different operators varied. The technique for operation of the MSRT was agreed on before the tests and compared after the tests. No apparent difference in method of operation was evident. A limited second set of tests was performed by Operator 1 after the operator-to-operator difference was observed. The front sides of the sun visors were retested by Operator 1 using MSRT S/N 001-stylus #3. The average difference in MSRT values between operators for this second set of tests was found to be 5 MSRT units. The difference in the average MSRT values for this second set of tests was only 0.7 MSRT units. Some values obtained by Operator 1 in the second set of tests were higher than and some values were lower than those obtained by Operator 2. The values obtained by Operator 1 in the second set of tests were all 25 to 50 MSRT units higher than he obtained in the first set of tests on the same visors. This result would indicate that the stylus of the MSRT had become less sharp.

TABLE 5: AVERAGE DIFFERENCE IN MSRT VALUES - OPERATOR TO OPERATOR

	STYLUS 3 FRONT	STYLUS 3 REAR	STYLUS 4 FRONT	STYLUS 4 REAR
VISOR TYPE	OP 1- OP 2	OP 1-OP 2	OP 1-OP 2	OP 1-OP 2
SUN	34.0	34.2	25.8	18.8
FV-6	35.3	34.3	38.0	31.3
BARNES	38.7	27.0	26.3	29.0

The stylus-to-stylus variations obtained by each operator (Figures 11 and 12) indicate that stylus #4 produced scratches more readily (produced lower MSRT values) than did stylus #3. This stylus-to-stylus variation was consistent from operator to operator, from manufacturer-to-manufacturer, and from front to rear of the visors. Although the two stylus tips were fabricated to be identical, the results indicate that stylus #4 had a sharper edge than did stylus #3. Microscopic examination of the stylus tips revealed that stylus #4 had a small imperfection or pit near the edge of the tip which had not been noticed before the tests were conducted.

The differences in the MSRT values obtained from the front to the rear surfaces of each type of visor are given in Table 6 and are illustrated in Figures 17 and 18. The differences from front to rear are greater for stylus #3 than for stylus #4. In general, both operators obtained higher MSRT values for the rear surfaces of the visors. The higher values obtained for the rear surfaces could be due to actual differences in coating hardness or could be caused by the concave shape of the rear surface compared to the

convex shape of the front surface. The reason for the differences from front to rear cannot be deduced from the data.

TABLE 6: AVERAGE DIFFERENCE IN MSRT VALUES - FRONT TO REAR

	STYLUS 3 OP1	STYLUS 4 OP 1	STYLUS 3 OP 2	STYLUS 4 OP 2
VISOR TYPE	FRONT to REAR	FRONT to REAR	FRONT to REAR	FRONT to REAR
SUN	11.2	6.2	13.0	6.2
FV-6	20.7	8.3	19.7	3.7
BARNES	12.3	1.3	6.7	4.7

CONCLUSIONS AND ANALYSIS

The results of the tests performed show that the MSRT can be used to measure the relative scratch resistance of optical hard coatings. The hard coating on Glendale FV-6 visors was found to be more scratch resistant than either the Gentex sun or Barnes visors by both operators using either stylus. Particular visors had more scratch resistant coatings than others. These visors were consistently measured as being more scratch resistant. The values obtained with the MSRT permit the comparison of the scratch resistance of one coating with another.

Coatings on the visors tested did not show significant variation of scratch resistance across a particular surface. The variations noted from front to rear surfaces will need to be investigated further to determine if the surface shape is influencing the MSRT values obtained.

Significant variability in absolute MSRT values was found for different styluses and for different operators. Differences in the stylus tips are suspected as being the cause for the variability in the MSRT values. The qualification of the MSRT as a method for obtaining an absolute measure of scratch resistance was not accomplished. The variation in values from operator to operator are probably related to changes in the stylus tips that occurred during the course of testing. The limited second set of tests performed indicates that consistent absolute measurements are possible if the stylus tip can be kept from dulling. Further tests performed by operators using the MSRT to consecutively test the same coating area will provide data to determine if stylus tip dulling is a factor. The stylus tips used for these initial tests were made of tungsten carbide. It may be necessary to make the tips from a harder material such as diamond.

The variation in absolute values obtained with the two different styluses which were fabricated to be identical indicate that better fabrication techniques are needed to duplicate the styluses from one unit to another. Consistent MSRT values must be

achieved from one stylus to the next in order to establish an absolute measure of scratch resistance. The MSRT values for stylus #4 were consistently lower than for stylus #3.

It may be possible and necessary to calibrate the MSRT stylus periodically using a known hard coating. A bias could be determined for a particular stylus or a particular operator and added to or subtracted from the MSRT values obtained with that stylus. If the average values given in Tables 3 and 4 are biased by a fixed amount for each of the styluses, the operator-to-operator variation (thought to be resultant from stylus tip dulling) is brought within acceptable limits. Tables 7 and 8 give the average MSRT values with a 35 unit bias added to Operator 1 values with stylus #3 and a 30 unit bias added to Operator 1 values with stylus #4. The average values obtained by the two operators after the bias is added are very consistent. Further testing will be necessary to confirm this.

TABLE 7: AVERAGE MSRT VALUES - OPERATOR 1 BIASED BY 35 UNITS
TESTER S/N 001 - STYLUS #3

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	76.8	75.8	88.0	87.2
FV-6	104.0	104.3	124.7	124.0
BARNES	74.3	78.0	86.7	78.7

TABLE 8: AVERAGE MSRT VALUES - OPERATOR 1 BIASED BY
30 UNITS TESTER S/N 002 - STYLUS #4

VISOR TYPE	FRONT OPERATOR 1	FRONT OPERATOR 2	REAR OPERATOR 1	REAR OPERATOR 2
SUN	65.0	60.8	71.2	60.0
FV-6	68.7	76.7	77.0	78.3
BARNES	41.3	37.7	40.7	39.7

It is concluded that an MSRT value of about 80 MSRT units for stylus #3 (or a unit referenced to stylus #3) can be considered to be an acceptable scratch resistant coating. Higher values are, however, desirable.

RECOMMENDATIONS

It is recommended that further testing be performed to qualify the MSRT as a method for measuring absolute scratch resistance values. A specific coated sample should be selected as the "standard" with which to calibrate the MSRT and the operator.

The application and validity of a calibration bias value should be further investigated. Tests should be performed on the same sample consecutively by the different operators to minimize the possibility of stylus tip dulling effects. More styluses should be fabricated with greater care to demonstrate stylus-to-stylus repeatability. Other materials that might be used as stylus tips should be investigated. The 60° right circular cylinder form of stylus tip is recommended for testing visors and other ophthalmic eyewear since it produces MSRT values in the desired range and is representative of the types of objects that cause scratches during use.

APPENDIX A

SUMMARY SPREADSHEETS

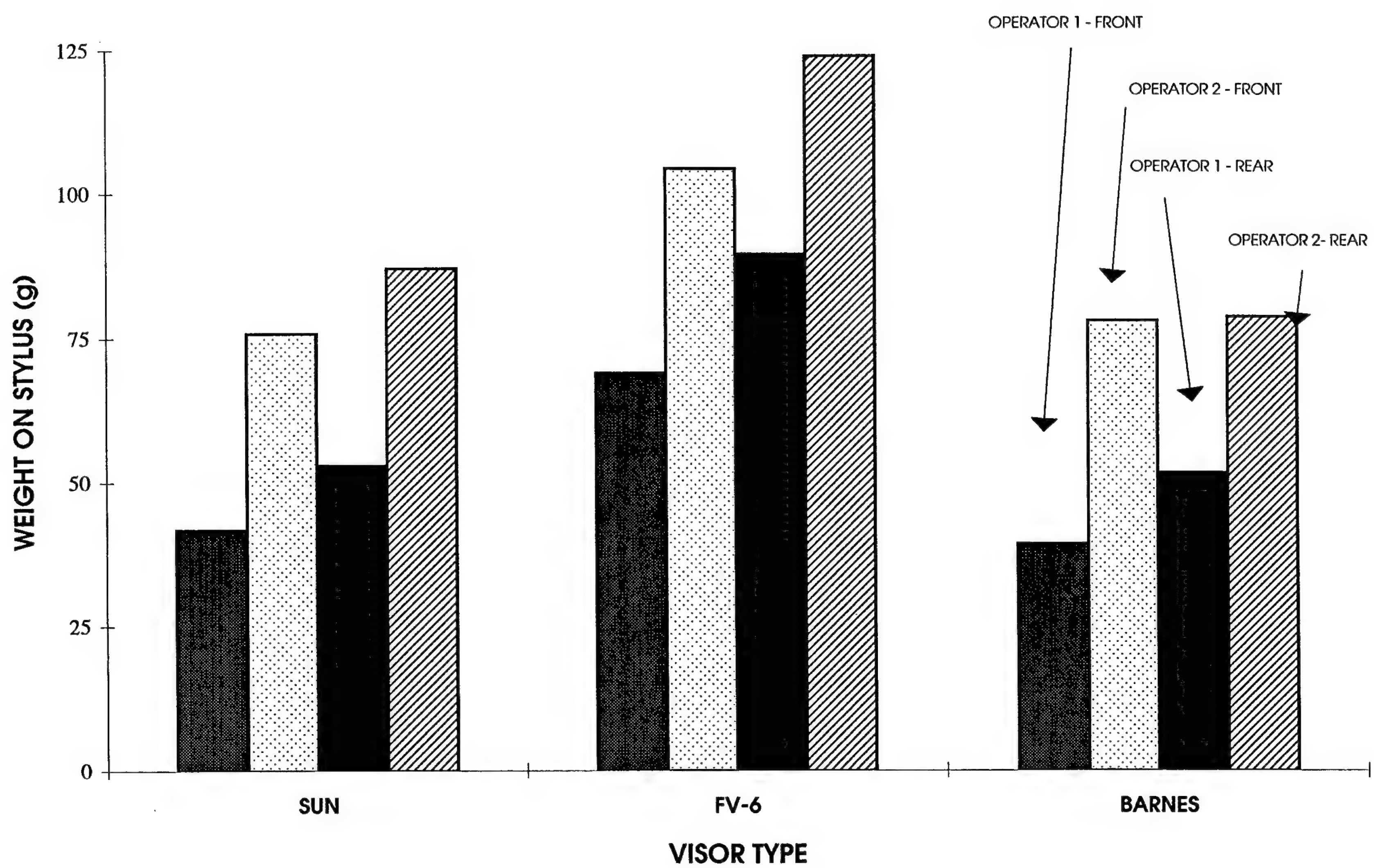

Figure A-1. Average weight on scratch tester to cause scratch - Maier tester with stylus 3.

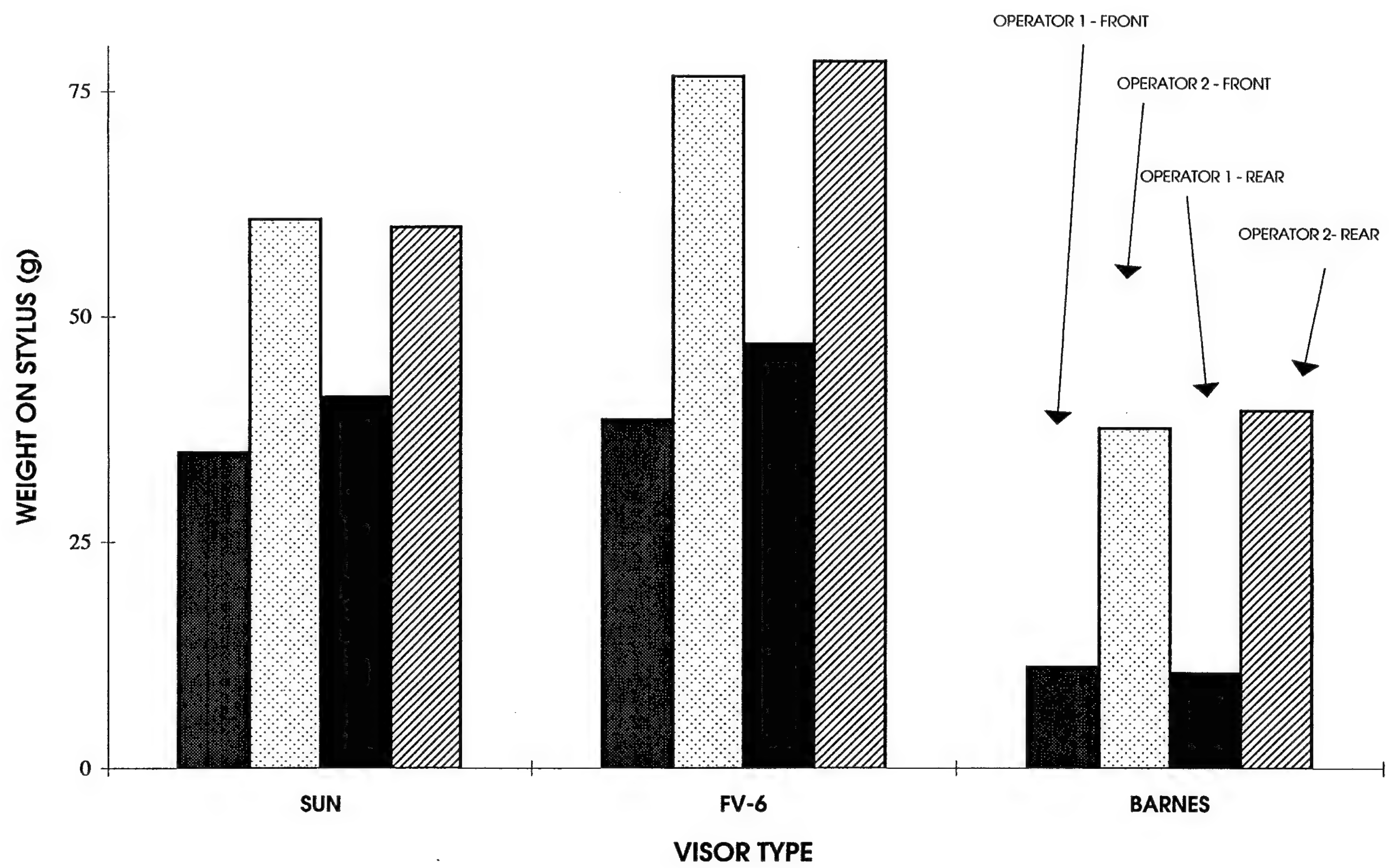

Figure A-2. Average weight on scratch tester to cause scratch - Maier tester with stylus 4.

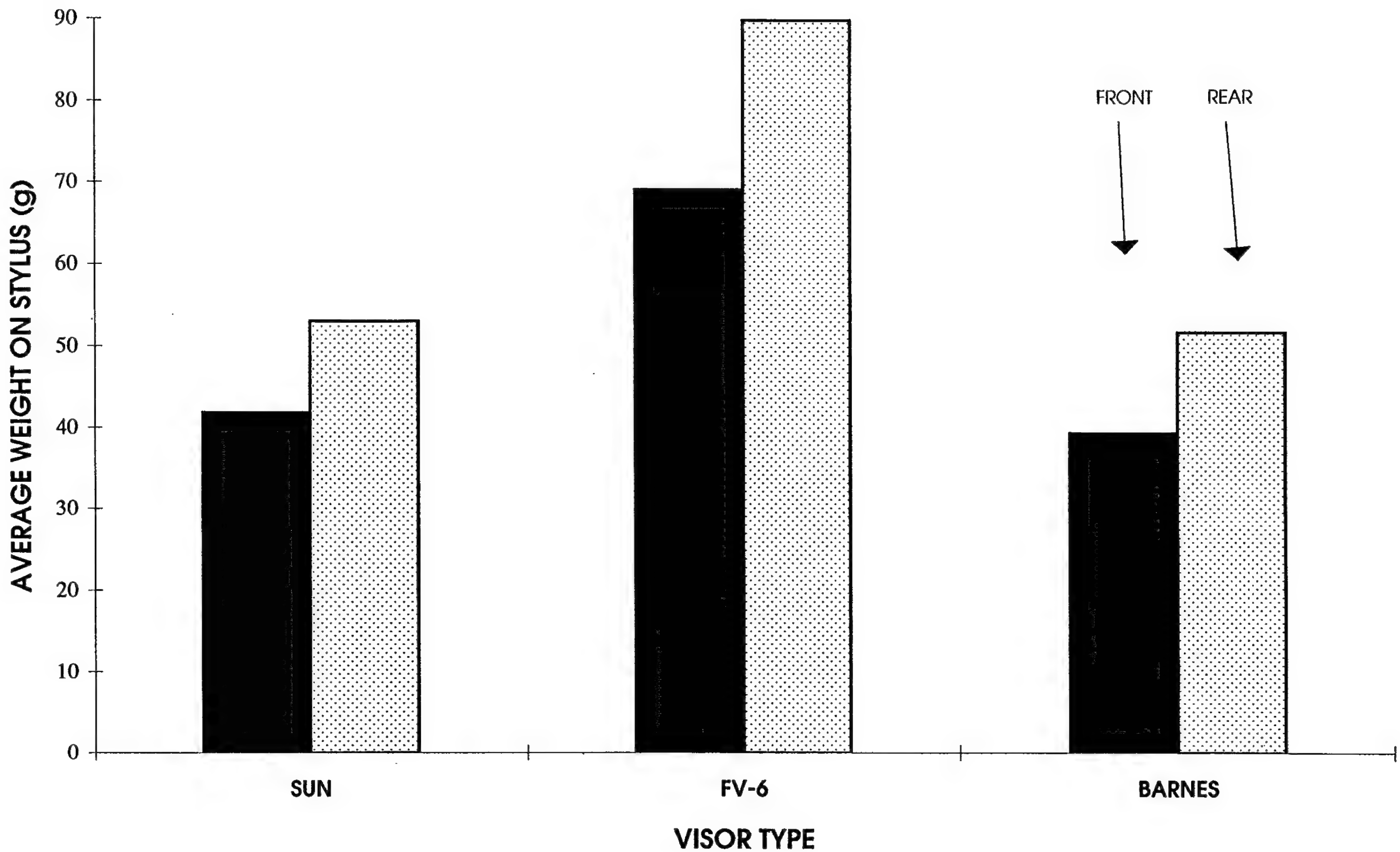

Figure A-3. Average MSRT values - manufacturer to manufacturer. Tester with stylus 3 - Operator 1.

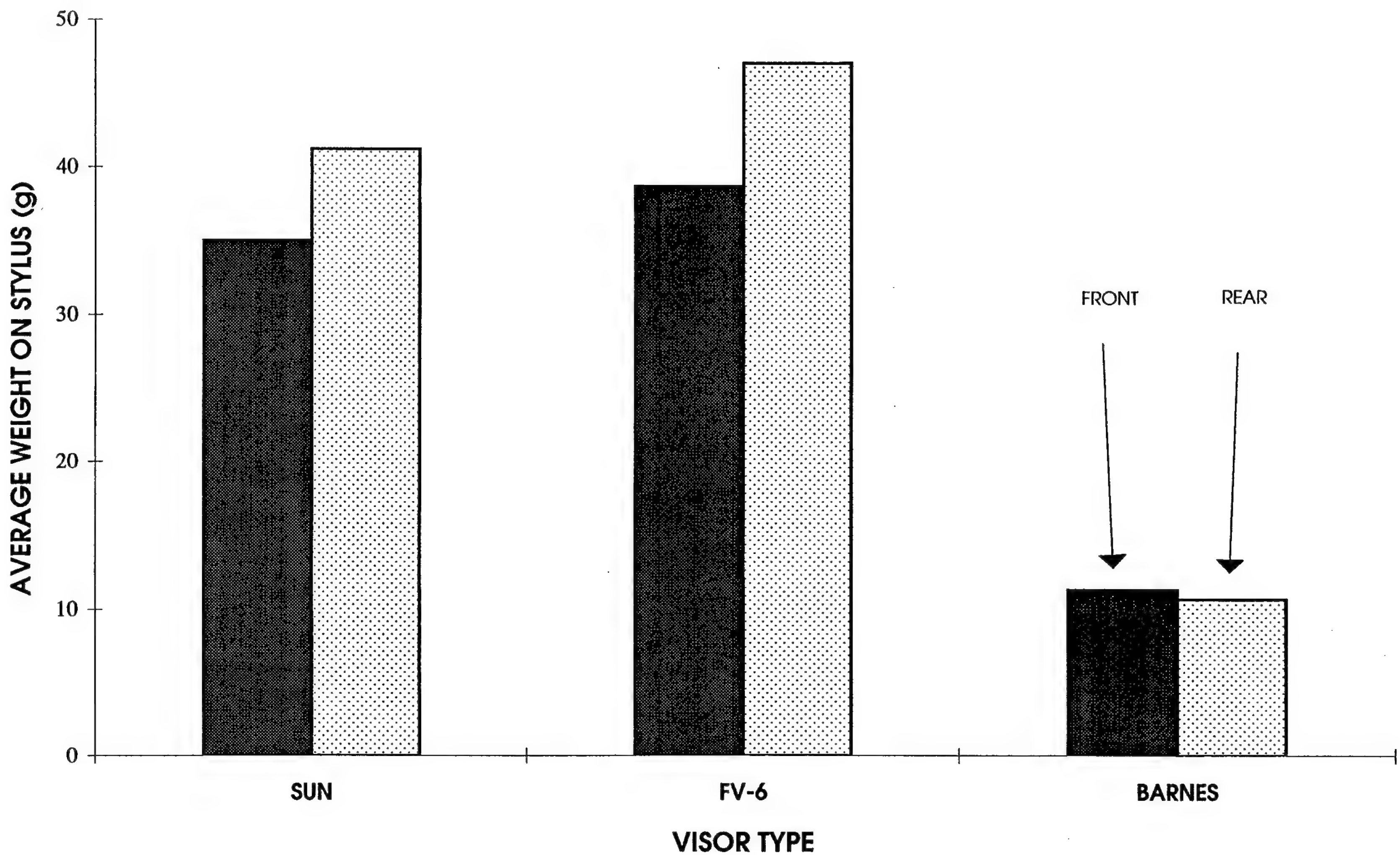

Figure A-4. Average MSRT values - manufacturer to manufacturer. Tester with stylus 4 - Operator 1.

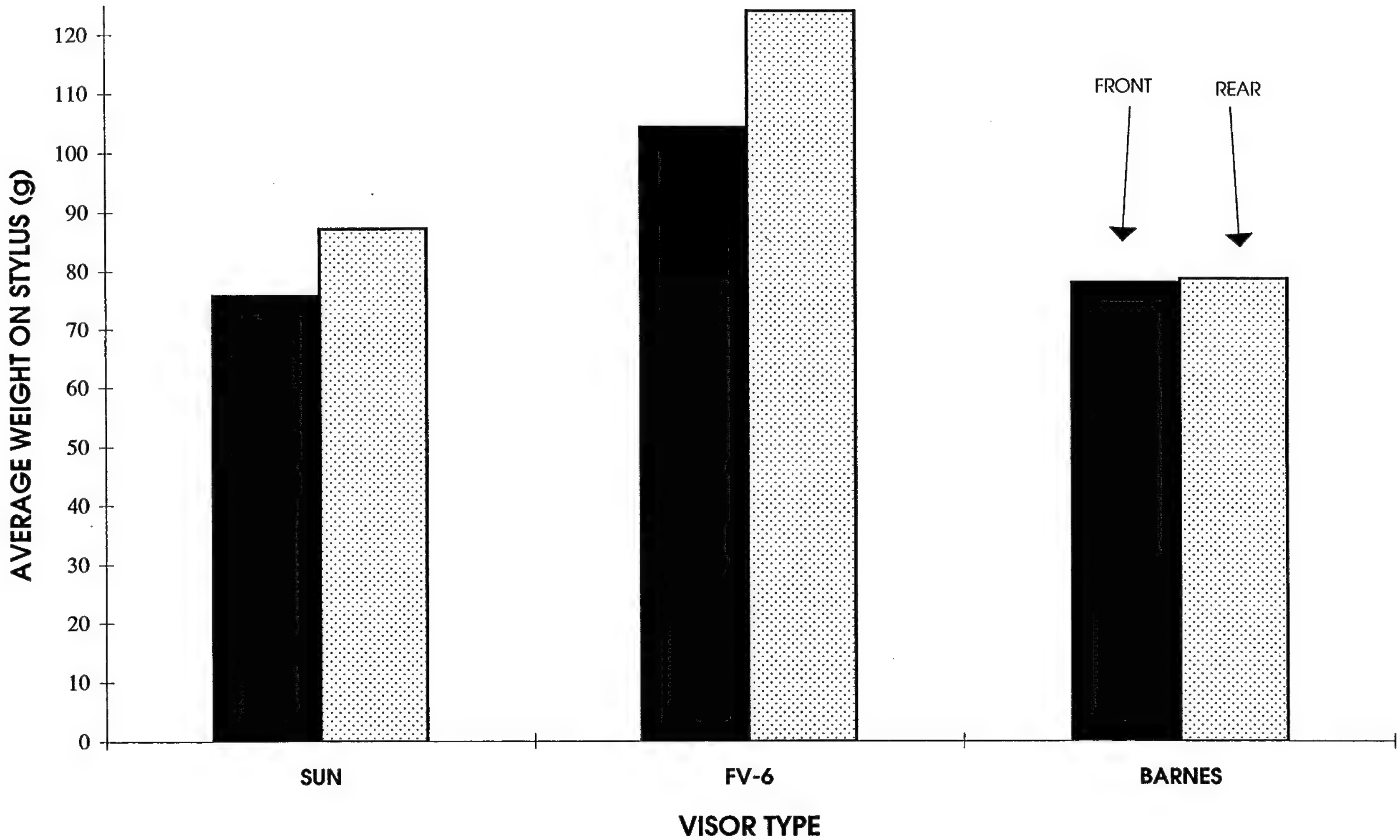

Figure A-5. Average MSRT values - manufacturer to manufacturer. Tester with stylus 3 - Operator 2.

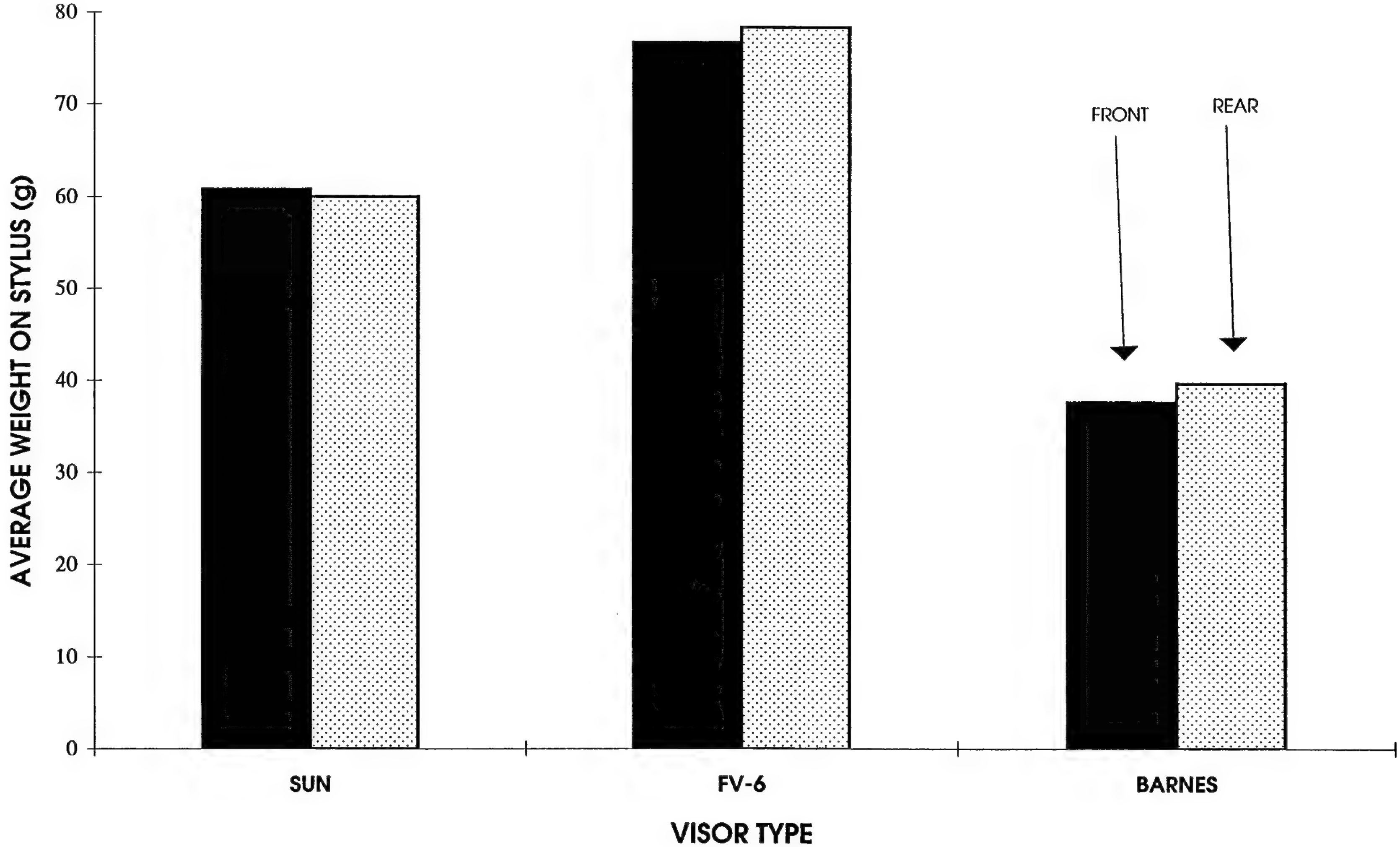

Figure A-6. Average MSRT values - manufacturer to manufacturer. Tester with stylus 4 - Operator 2.

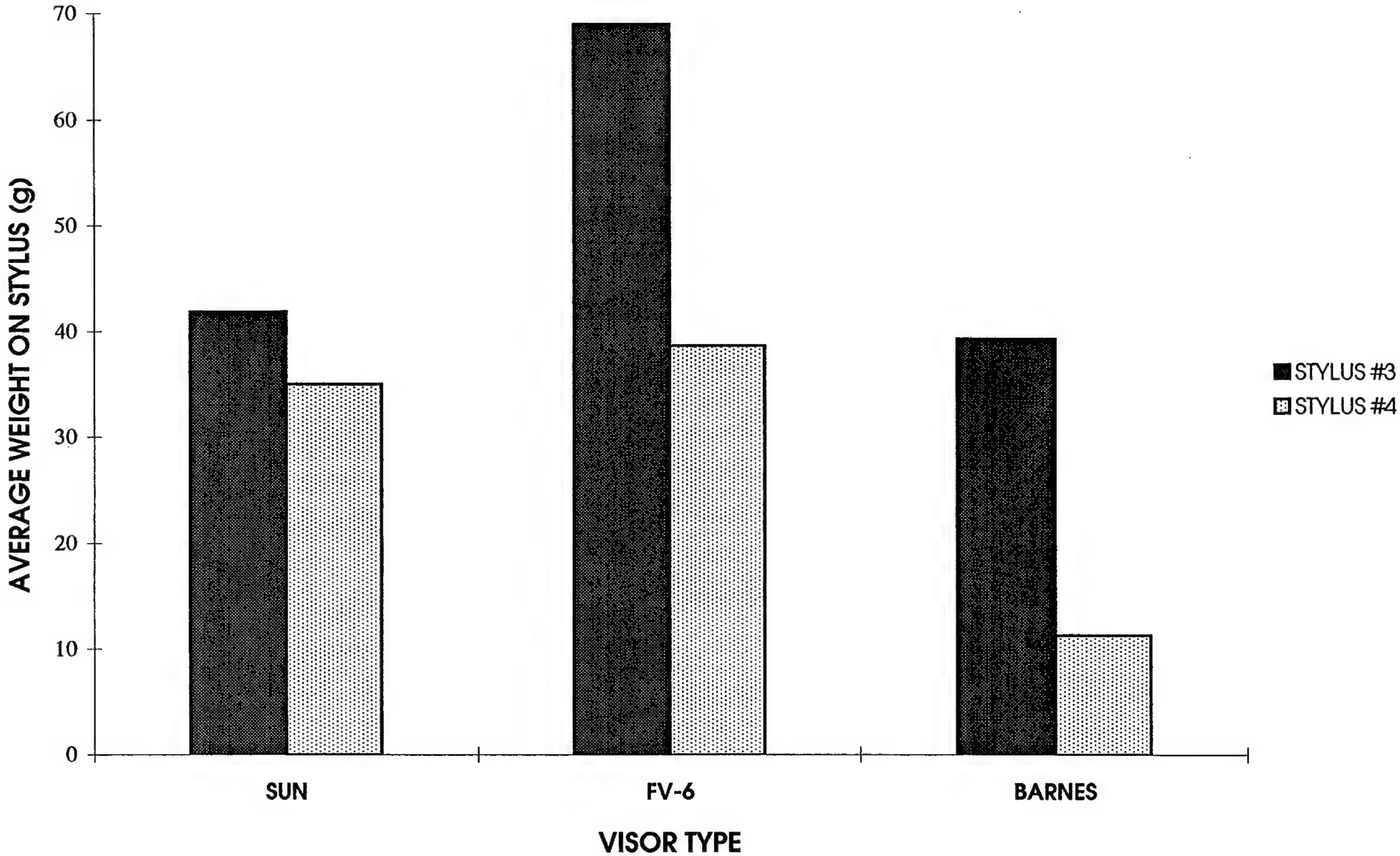

Figure A-7. Average MSRT values - stylus to stylus. Front of visors - Operator 1.

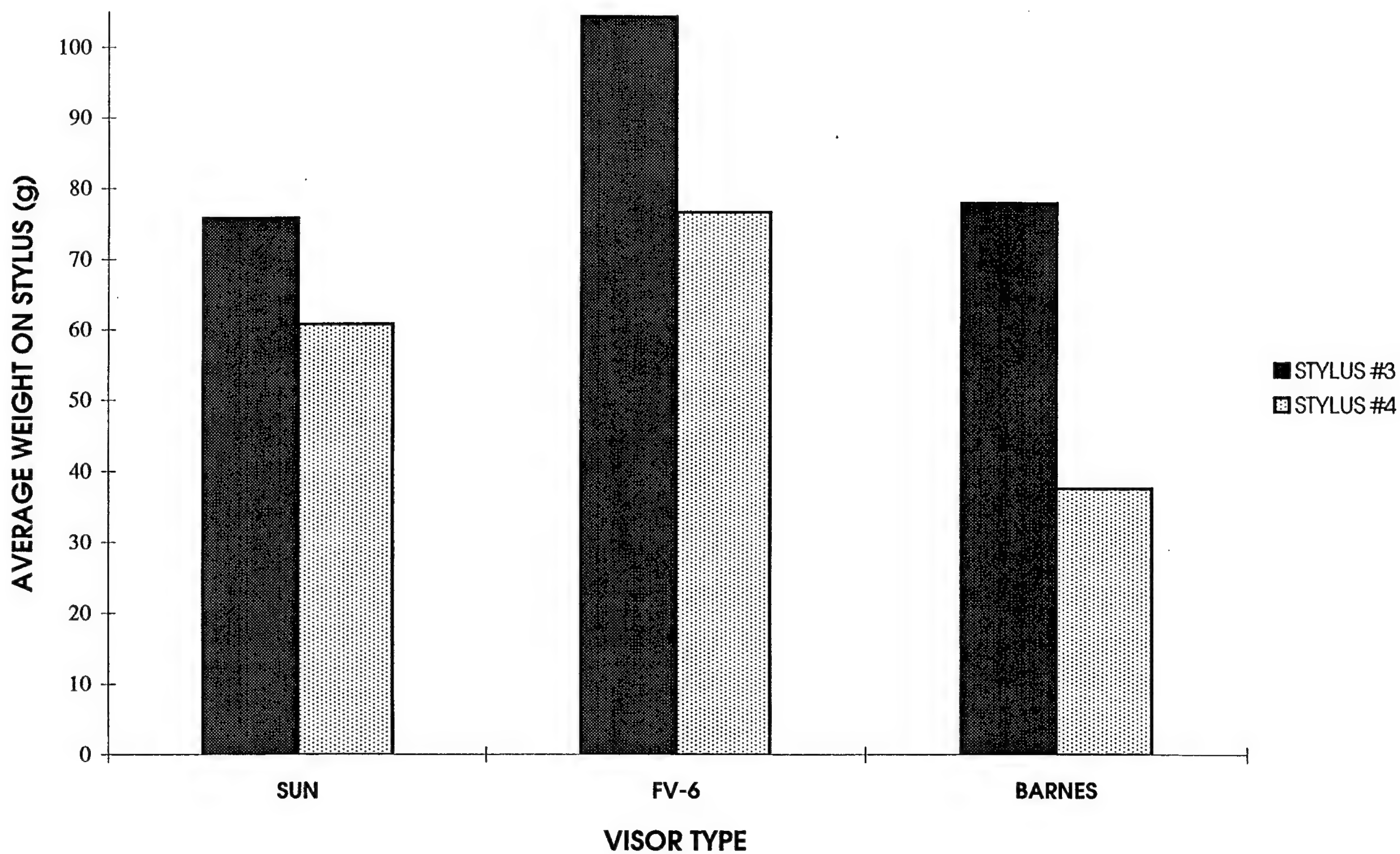

Figure A-8. Average MSRT values - stylus to stylus. Front of visors - Operator 2.

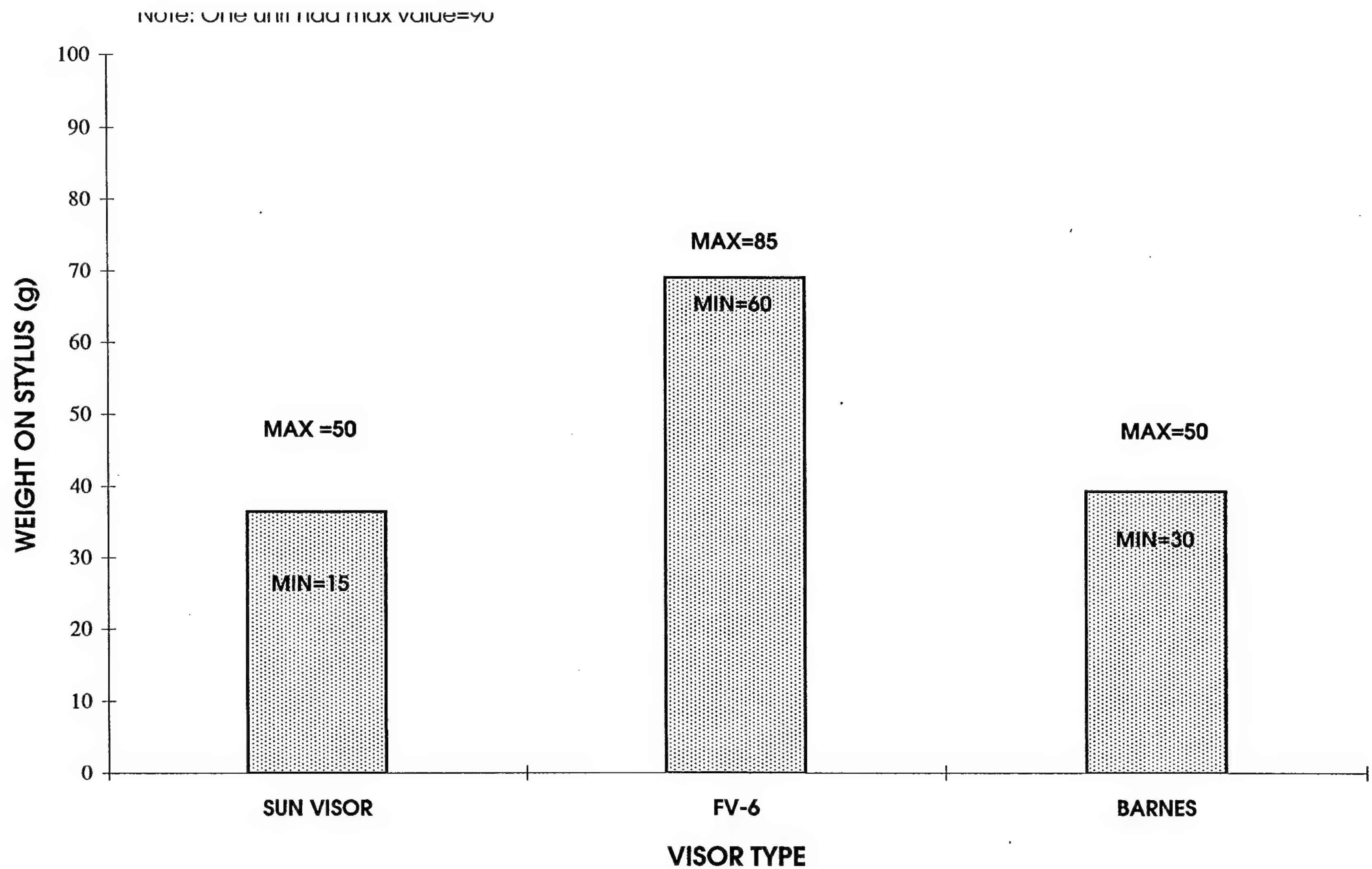

Figure A-9. Average weight on scratch tester to cause scratch. Tester with stylus 3 - Operator 1 - front side.

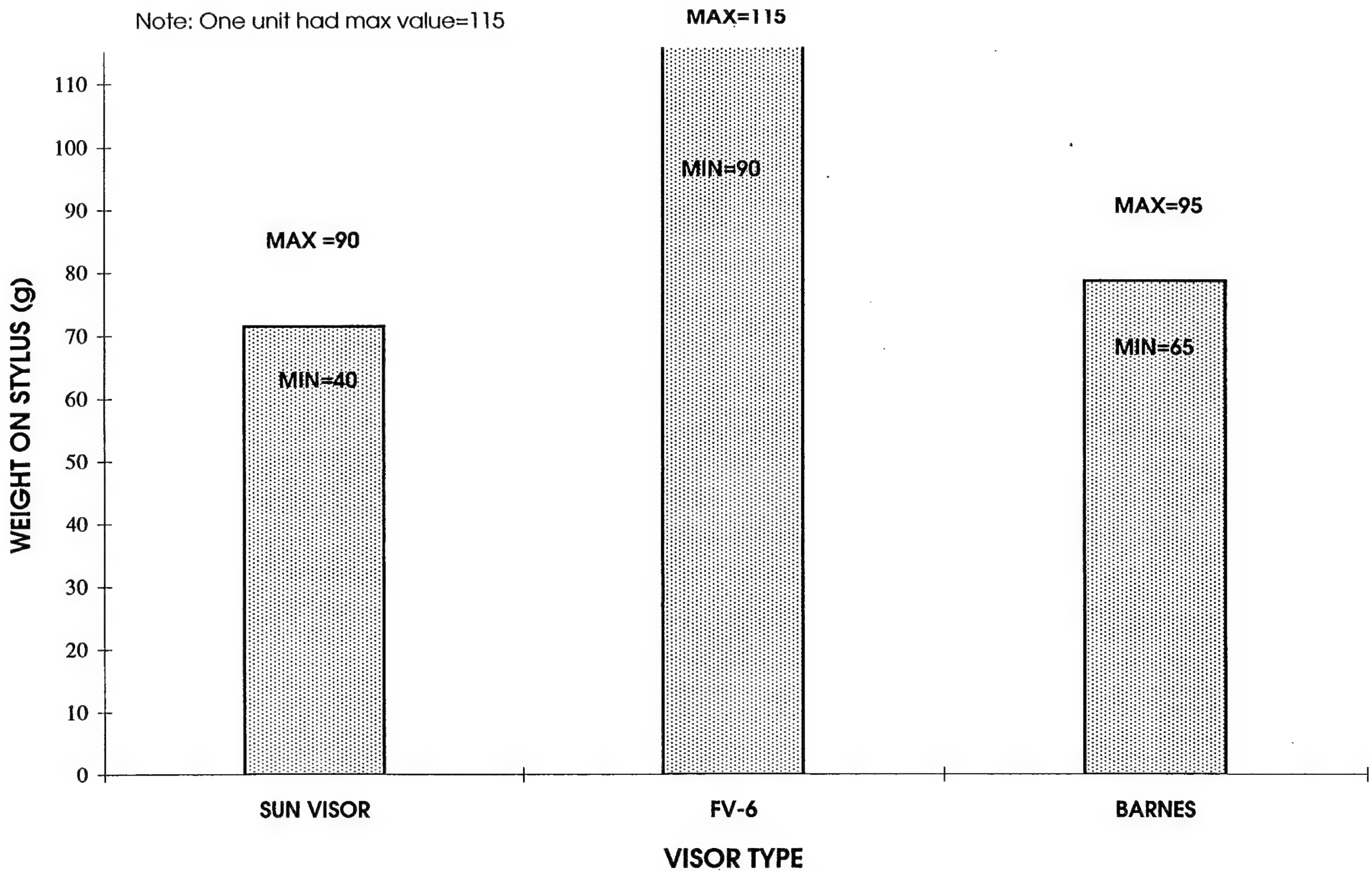

Figure A-10. Average weight on scratch tester to cause scratch. Tester with stylus 3 - Operator 2 - front side.

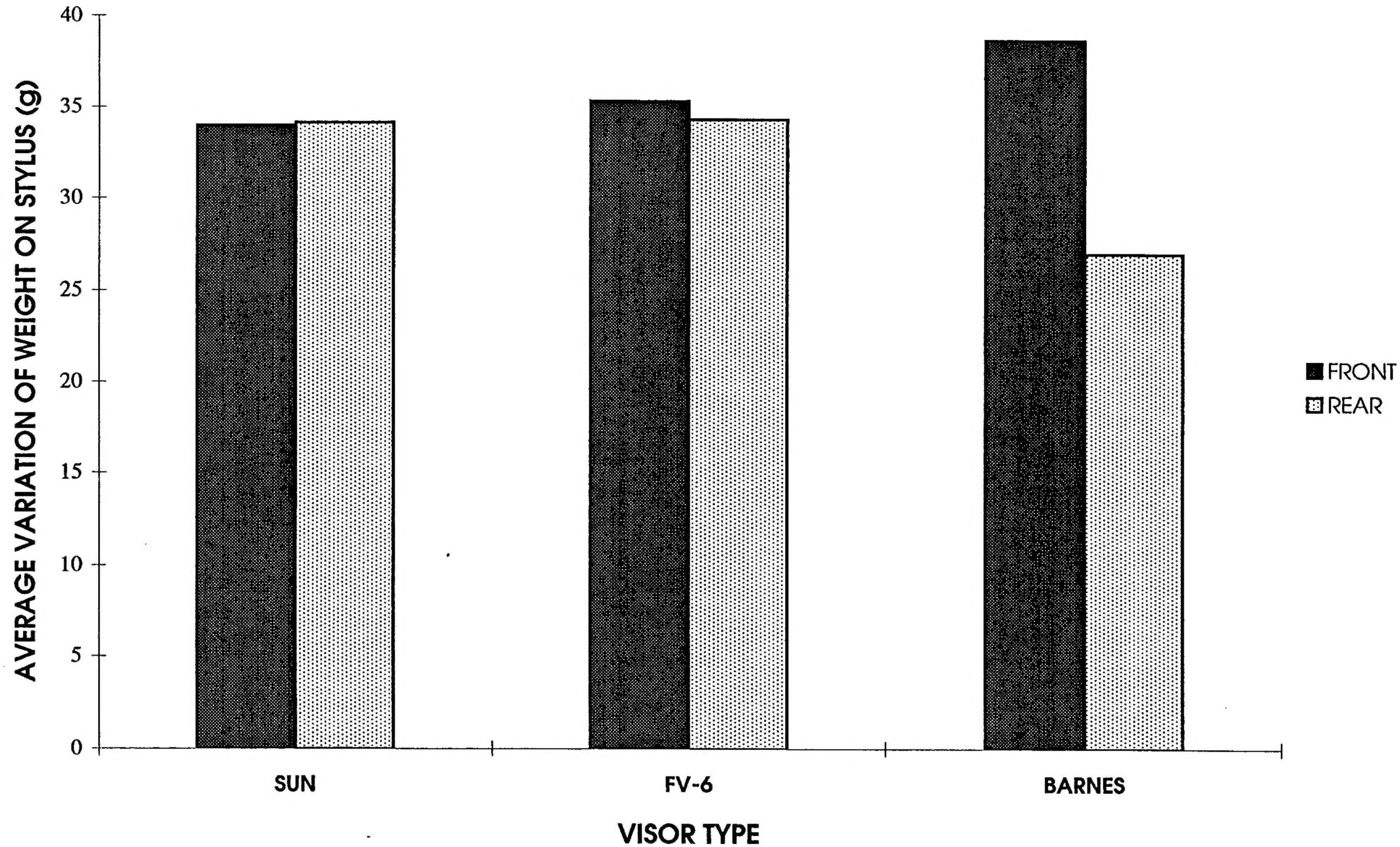

Figure A-11. Average variation of MSRT value s- operator to operator. Tester with stylus 3.

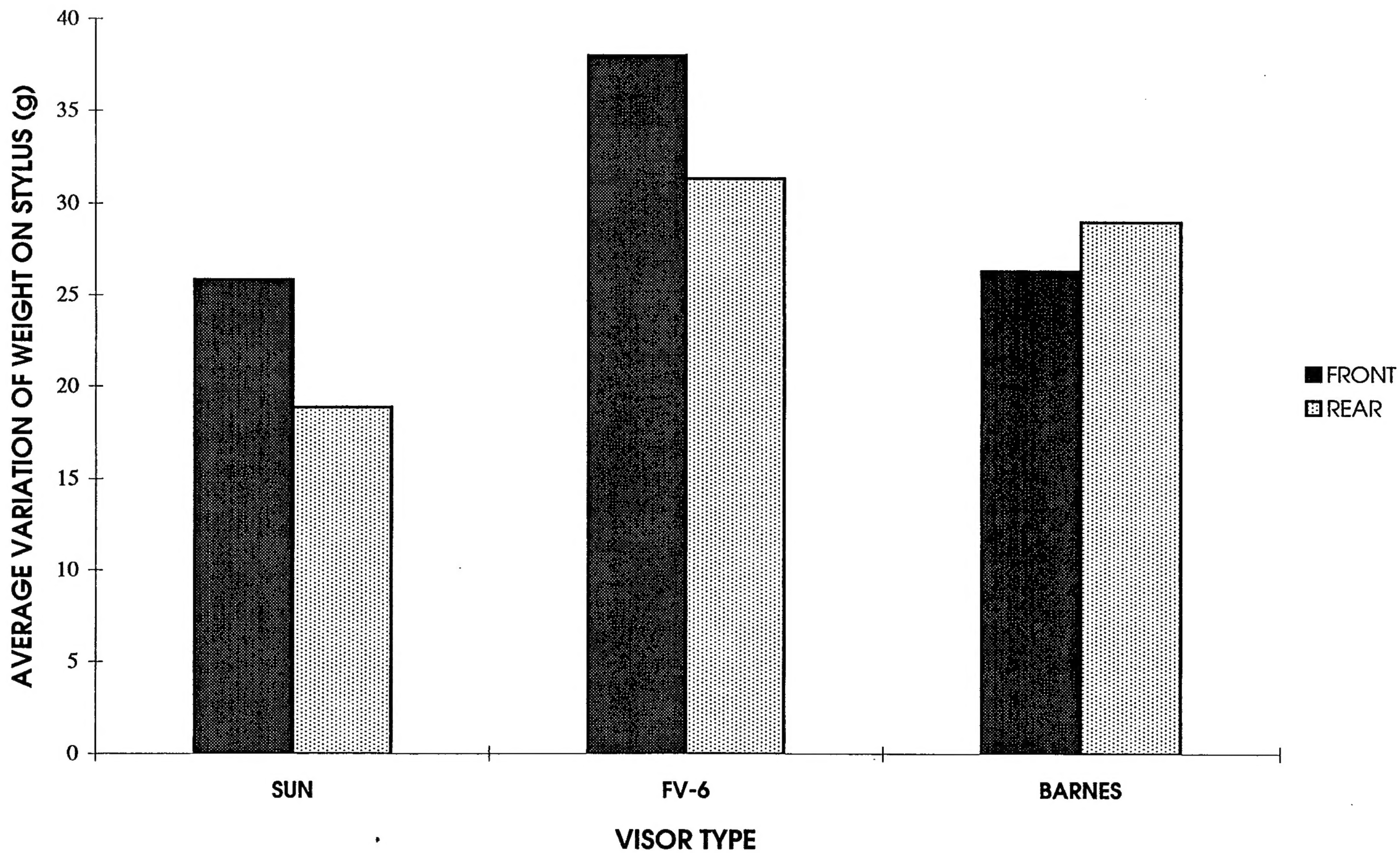

Figure A-12. Average variation of MSRT values - operator to operator. Tester with stylus 4.

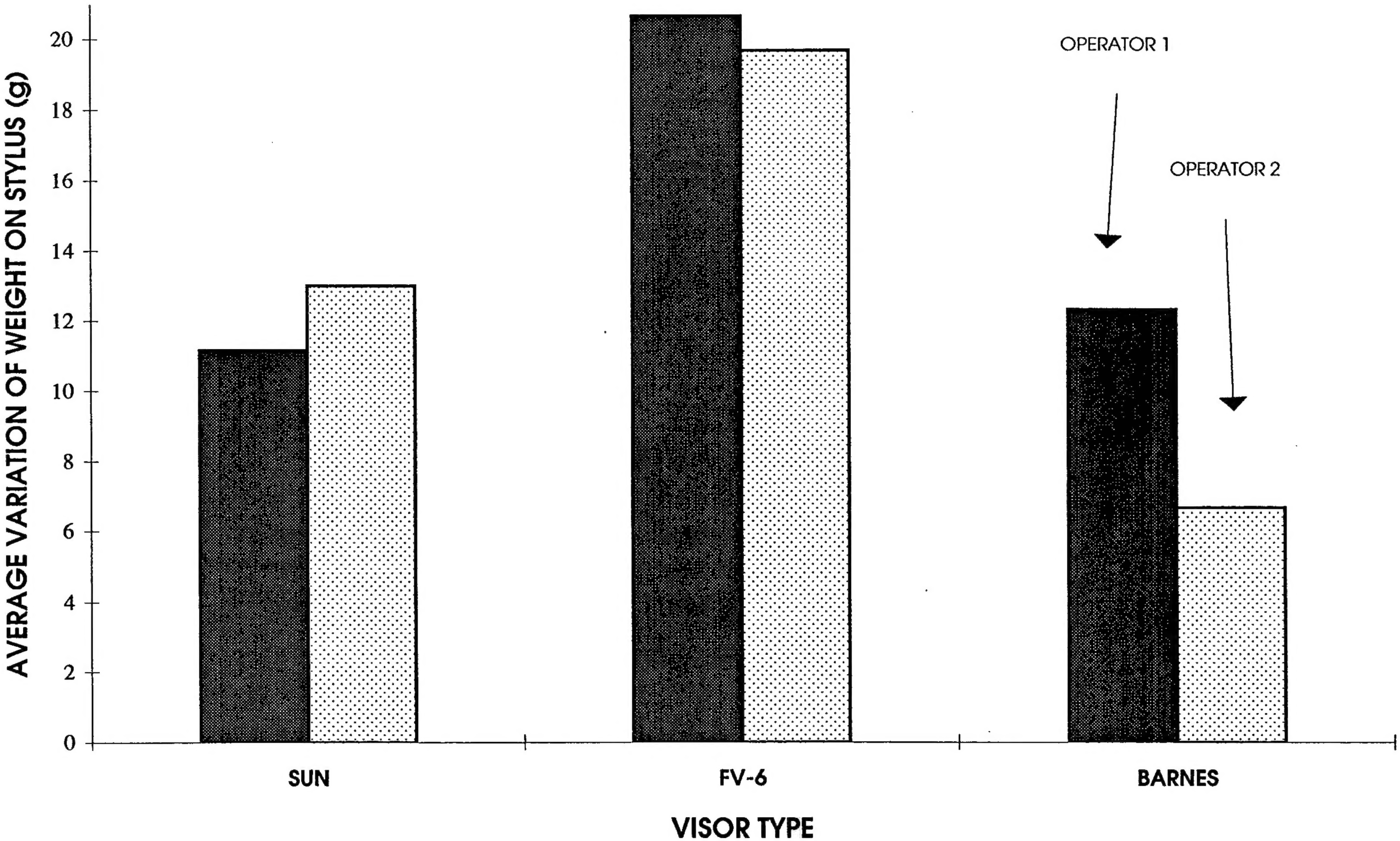

Figure A-13. Average difference of MSRT values - front to rear. Tester with stylus 3.

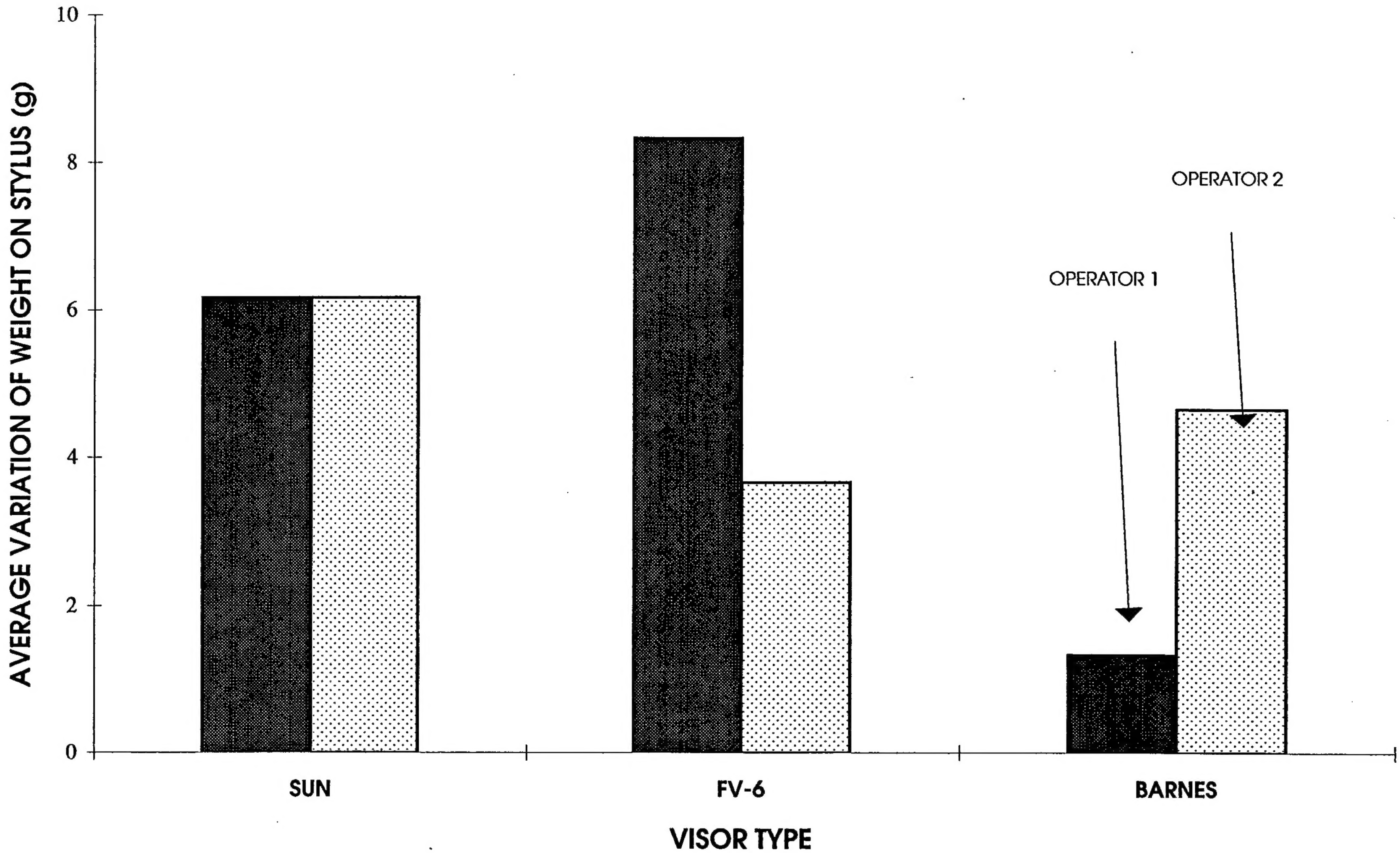

Figure A-14. Average difference of MSRT values - front to rear. Tester with stylus 4.